The Perspectives of Laboratory Dusty Plasmas for the Applications in Astrophysics

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Abstract. It is very well known fact that dust and dusty plasmas are ubiquitous in the space: from interstellar media, to cometary dust, planetary rings and so on. The phenomena concerning the dust in space, seems to have an immense number of facets. The help for the identification of some of the phenomena, or tracing the new ones, has coming during last few decades more and more from the physics of dusty plasmas. We present an overview on the development in the application of laboratory dusty plasmas seizing from the production of interstellar analogs, investigations connected with the field of the interplanetary dust and planet-formation, charging phenomena and their future possibilities of the dusty plasma applications in this field.

Keywords: laboratory research, dust particles, interstellar medium, planetary dust, dusty plasma
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INTRODUCTION

Although it is certainly hard to recreate astro-conditions in the laboratory, there is maybe not a long history, but certainly a long list of successful laboratory investigations with applications in the field of astrophysics, from plasma astrophysics, dust investigations to particle astrophysics and cosmology. There is also an extremely active and huge community oriented towards investigations on dust in space. This is easy to understand if we keep in mind the omnipresence of dust: from interstellar media, to cometary dust, planetary rings and so on. The phenomena concerning the dust in space seem to have an immense number of facets (the role of dust for radiation processing, star formation, planet formation, etc). In particular (and briefly), interstellar dust regulates star formation, catalyzes the production of molecules, and reprocesses UV and optical radiation. The existence and characteristics of dust can be observed spectroscopically all throughout the spectral regions - from VUV to far infrared- through scattering, absorption, extinction, and polarization effects. The first experimental investigations started far away in history with the material analysis of meteorites collected on Earth [1]. Since that time, the

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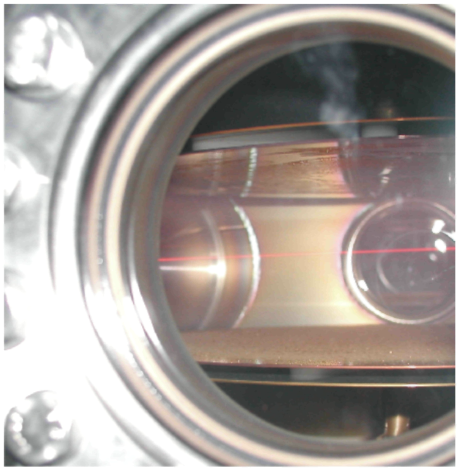
progress in the astro-field was triggered by the development of observational facilities which resulted in a huge amount of new data (e.g. airborne facilities nowadays) and at the same time, increased the laboratory investigation possibilities.
Contemporary investigations in the field of astrophysics of dust deal with the analysis of collected dust particles (interplanetary dust, cometary and meteoritic grains), with the production and analysis of various laboratory dust analogs, with the "mineralogy" of dust particles, with the study of reactions of molecules and ions in the gas phase and on grain surfaces, with the interaction of dust grains with different radiations and with the charging and agglomeration of dust particles [2,3 4]. The analysis of the latter processes is of special importance for the understanding of planet formation, a topic that have attracted great attention due to the discovery of exoplanets.
There is even more: the laboratory moved to space, e. g. PKE experiments [5], or experiments with ice residues exposed to irradiation in space aboard the Exobiology Radiation Assembly (ERA) platform on the EURECA satellite [6].
The theories, methods and materials obtained in the laboratory dusty plasmas for the astrophysical applications have been described e.g. by [7, 8]
It is also important to stress the basis for our work: significant components of interstellar/planetary dust are carbonaceous components, and the understanding of the composition and structure of such materials is therefore of key importance (see for review [2]). We present here a short overview of the experimental work obtained in low temperature radiofrequency (rf) dust forming plasmas: gas phase polymerization of carbonaceous dust, in situ extinction experiments, the influence of gas temperature on the polymerisation process and the resultant particles.

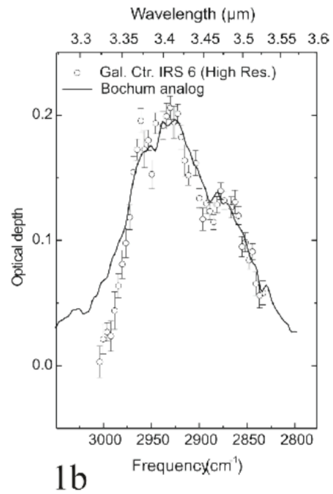
Experimental Results and Discussion

Low temperature, low pressure rf plasmas are an ideal source for the polymerization of dust particles. Moreover they provide an excellent trap for the charged dust particles (Figure 1a) laser light scattered on the levitating dust particles), enabling different in-situ methods like in-situ extinction measurements on the dust particles (from VUV to IR spectroscopy), mass spectroscopy and optical emission spectroscopy of gas phase species etc. The plasma polymerization process and experimental set up used in our work are in detail described elsewhere [8, 9]. It is possible to claim that such polymerization process posses similarities to stellar outflow conditions [9,10] and provides a convenient way to make candidate carbonaceous interstellar dust analogs under controlled conditions and to compare their characteristics to astronomical observations [8, 11].
The observation of the gas phase provided us with the information on the species important for the nucleation and growth of the dust particles in the hydrocarbon plasma [12, 13] being in good agreement with the assumptions made in astrophysics, based on observational methods (see for explanation [13]).
The results observed from the in-situ IR spectroscopy seamed to be even more interesting. The IR spectrum of carbonaceous dust in the diffuse interstellar medium is characterized by a strong 3.4 μm C-H stretching band and weak 6.8 and 7.2 μm C-H bending bands, with little evidence for the presence of oxygen in the form of carbonyl (C=O) or hydroxide (OH) groups. We can see from the Figure 1b) that the plasma

polymerization products produced under oxygen-poor conditions provide a good comparison to the peak position and profiles of the observed diffuse dust IR spectrum (example for 3.4 μm feature, for further IR criteria see [2]).



1a



1b

FIGURE 1. a) Particles trapped in a gaseous argon matrix (red line- He-Ne laser beam scattered on the cluster); b) IR spectral comparisons: lab data (line), observational data (points)

Another prominent example for a dust feature is the absorption bump at 217.5 nm. Long after the discovery of this ubiquitous UV extinction band [14], the strongest known interstellar feature, its physical origin remains one of the most challenging astrophysical problems. Its peak position is extremely stable, while the bandwidth can vary depending on the environment [15]. All recent results point strongly towards a carbonaceous carrier for the UV bump and among those hydrogenated amorphous carbon (HAC) seems to be the most favored [16]. Following [17] sp^3 components in carbon grains are responsible for the 3.4 μm feature while the 217.5 nm bump originates from the sp^2 bonded component. The results of our in-situ VUV extinction measurements on dust polymerized in argon/acetylene gas mixture (presented detailed in [13] are shown in Figure 2a. The black symbols represent a measurement performed for 20nm particles, the red symbols a measurement performed for 100nm particles. Both curves are normalized to the intensity at 250 nm. Figure 2 b) and c) show the extinction efficiencies (calculated with BHMIE) for the wavelength interval 140 – 260 nm (normalized to one at 250 nm). The calculation for different particle radii is made in both cases for carbonaceous materials with a complex refraction index n taken from [18], for b) hydrogen poor material, for c) hydrogen rich material. A comparison between figures 2a), b) and c), shows strong similarities between our measurements in 2a) and the data shown in 2c). In both cases the curves are increasing towards smaller wavelengths and the increase is in both cases stronger for smaller particles. Although it is difficult to compare materials produced in different processes, one may conclude that the hydrogen content within the plasma polymerized particles is too high to get a pronounced extinction bump in the UV-region. The solution can come from an increase of the sp^2 sites in the material, for example by changing the plasma composition [9] or by annealing. One important direction in our further work will concern the role of the gas temperature for the nucleation processes and the material characteristics. The temperature aspect, especially cooling, is highly interesting, especially after the results presented recently [19].

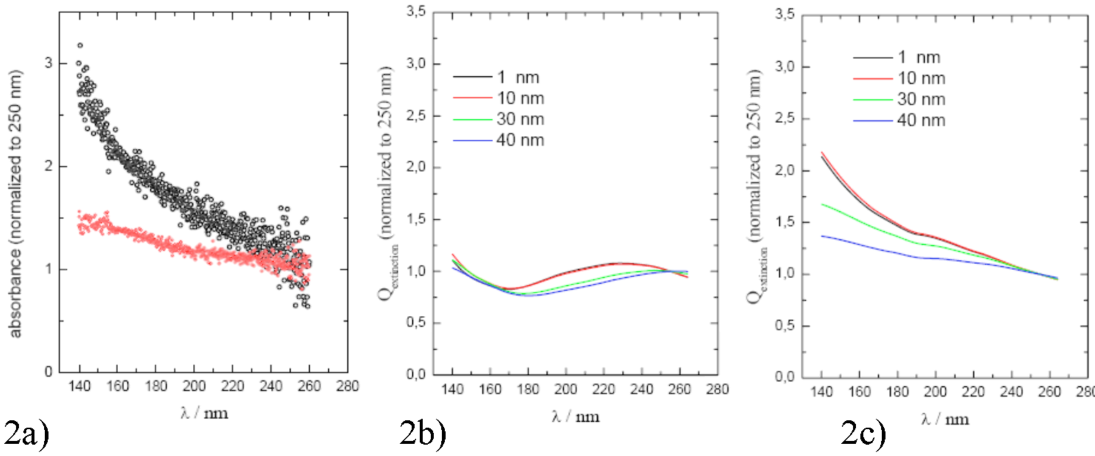


FIGURE 2. a)Extinction curves of particles produced in a mixture of argon and acetylene. The black symbols: a measurement performed for small particles (20nm), the red symbols:100nm particles. b) and c) Extinction curves for different particle radii for two different materials. b) shows hydrogen poor material, c) hydrogenh rich material. Refraction indices necessary for these calculations are taken from [18]. All curves are normalized to value at 250 nm

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